A Reliable and Repeatable Method For Volume Calculation of Pressurized Garments

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ABSTRACT *A rapid, accurate and efficient method to conduct inflation, volume and leak tests on pressure containing personal protective garments was developed and validated. The new system consists of a computer data acquisition and process control system that integrates flow rate over time to calculate volume. Validation of the new test system was accomplished by comparing the volumes calculated by the computer with volumes actually measured via a wet spirometer. Results from the validation study showed that the computerized system was highly accurate. In addition, the computerized system allows suits to be rapidly and effectively evaluated.*

INTRODUCTION The development and testing of pressure containing personal protective garments like anti-G suits requires that rapid and accurate testing be conducted to determine leak rates, inflation rates, and other pressure related parameters. A number of test methods are available to conduct these evaluations; however, each has specific characteristics that limit their usefulness in the laboratory environment.

Initial approaches for volume calculations involved the use of the Ideal Gas Law. By regulating the air flow such that pressure changes are made in small pressure differentials, the conservation of mass relationship can be utilized for volume determination.[1] This approach, although valid, has proven to be time consuming and cumbersome. In addition, limitations of a closed system rule out the ability to use an anti-G valve for rapid inflation testing, eliminating an operationally relevant portion of the G-protection system.

A second approach required the use of a wet spirometer for calculating volume displacement. Using this method, the pressure garment was inflated to a predetermined pressure, disconnected from the inflation test stand and then connected to the inlet hose of the wet spirometer. At this point, the garment released the air into the spirometer and the volume was determined by a measurable displacement. This method has also proven to be valid, but the possibility of leaks during interconnections between the inflation apparatus and the wet spirometer forced the need for a leak-free and rapid method of volume calculation.

The proposed method of volume calculation required monitoring the air flow rate into the pressurized garment using an electronic flow meter. Initially a strip chart recorder was used to record the inflation characteristics of an anti-G suit. These characteristics included the inflation flow rate into the anti-G suit and pressures of various portions of the anti-G suit. From integral calculus, it is known that the integral of the flow rate function over time would determine the volume of air the anti-G suit required during the inflation process. Since the equation of the function for flow rate was not known, the integral was computed using the trapezoidal method of integration. In order to minimize the amount of error in this calculation, without over-sampling, a sampling rate of 25 hertz for the flow rate was used. Since incremental numerical data of this type was difficult to extract from a strip chart recording, an alternative method of data collection was required. One method more suited for calculations of this nature was a computer data acquisition system. The design and verification of this data acquisition process control system is reported herein.

SYSTEM CONFIGURATION The data acquisition system consisted of two categories: hardware and software. The hardware was composed of the required number of pressure transducers, a mass flow meter, an anti-G valve, a solenoid valve, interconnection hoses and a microcomputer. The software consisted of a program written in LABView ® 2. The hardware configuration can be seen in Figure 1.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 1993	Interim - May 1993-November 1993

4. TITLE AND SUBTITLE

A Reliable and Repeatable Method For Volume Calculation of Pressurized Garments

5. FUNDING NUMBERS

C - F33615-92-C-0018
PE - 62202F
PR - 2830
TA - 01
WU- 08

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

KRUG Life Sciences, Inc.
San Antonio Division
P. O. Box 790644
San Antonio, TX 78279-0644

8. PERFORMING ORGANIZATION REPORT NUMBER

AL/CF-PC-1993-0051

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Armstrong Laboratory (AFMC)
Crew Systems Directorate
Crew Technology Division
2504 D Drive, Suite 1
Brooks Air Force Base, TX 78235-5104

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

Proceedings: 31st Annual SAFE Symposium

11. SUPPLEMENTARY NOTES

Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

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14. SUBJECT TERMS

Air volume calculation, Pressurized garments

15. NUMBER OF PAGES

4

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

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A pressurized tank was used as an air source and was fitted with an adjustable pressure regulator set at 70 psi output. This setting was used to mimic the pressure source delivered to anti-G suits in operational use. Connected to the regulated air source was a solenoid valve that was computer controlled. When the valve was opened, inflation of the anti-G suit was initiated. Down line from the solenoid valve was the anti-G valve. In order to obtain maximum air flow through the anti-G valve, weights equivalent to +9Gz are applied to the anti-G valve's gravitational load port. Any air pressure in excess of 10.5 psig was vented to atmosphere from the outlet port of the anti-G valve. Air flow that was not vented to atmosphere was registered as it passed the mass flow meter into the pressure garment. To measure suit pressures, four pressure transducers were placed in strategic locations in the anti-G suit. Important pressure points for an anti-G suit were determined to be at the hose inlet, abdominal bladder, lower right and left calf areas. The copper and high pressure flex tubing used to supply air to the anti-G suit have a minimum inside diameter of 0.22". The system configuration was controlled and monitored by a Macintosh ® II series microcomputer with an onboard National Instruments NB-MIO-16 multipurpose data acquisition board driven by a program written in the LABView ® 2 software language. The system was designed to monitor the inflation and the deflation of the anti-G suit, collect data during these processes, and store the data in files. The computer receives 5 data signals from the test stand configuration, mass flow from the flow meter that produces a 0 - 5 volt output that is proportional to a 0 - 40 standard cubic foot per minute (scfm) flow range and input from four pressure transducers producing a 0 - 5 volt output signal that is proportional to a 0-12.5 psi range. The sole signal sent from the microcomputer to the test stand configuration opens or closes the solenoid valve.

OPERATION To conduct an anti-G suit test, three graphical user interface panels are used to initialize, activate and display all information during a test run. Panel 1 allows the operator to set all test parameters for a given test. The operator enters the high pressure, low pressure, timer cut-off, desired numbers of cycles and operational information into the input indicators of Panel 1 (Figure 2). The high pressure setting controls the inflation portion of the test run and is monitored from the left calf pressure transducer. When the transducer senses a pressure equal to or greater than the selected high pressure value, the computer closes the solenoid valve and the inflation portion of the test is terminated.

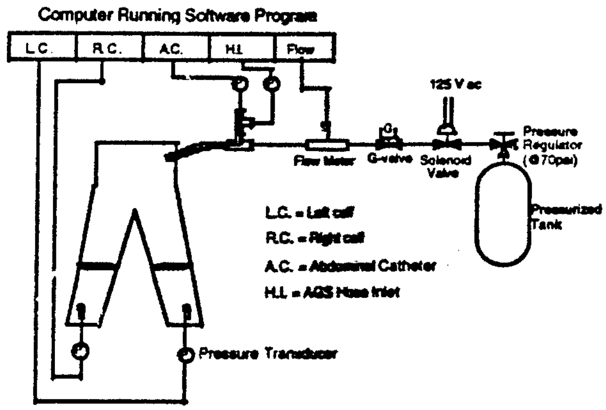

Figure 1. Hardware Configuration

The low pressure value controls the deflation portion of the program. After the anti-G suit has been pressurized to the level indicated by the high pressure value, the deflation portion of the program commences. The deflation pressure of the anti-G suit is compared to the low pressure value set by the operator. If the suit pressure becomes less than the low pressure value before the set time has elapsed, the suit is deemed unacceptable and the program will stop. If this does not occur the program will stop after 60 seconds and the pressure drop for this time period is computed.

The timer cut-off value is the maximum number of seconds the inflation portion of the program will last. The timer cut-off value will terminate the inflation process regardless of the left calf pressure reading and is used to prevent over inflation of the anti-G suit. The desired number of cycles value allows the operator to perform a pre-designated number of runs consecutively without reinitializing the program. A comment box allows the operator to add information to the data file such as anti-G suit serial number, suit size, and other hardware parameters.

Once the proper information has been entered into Panel 1, the Go arrow initiates the program. The user is then prompted to enter the filename in which the data will be stored. Two additional user interface panels are used to calibrate and initialize the flow meter and four pressure transducers. When calibration is completed, the

panels are deactivated by the operator. This will initiate the first inflation of the anti-G suit.

Panel 1 is then reactivated. Here the operator can view the pressures monitored by the pressure transducers during the inflation process. Once the inflation process is over, the deflation process begins. The deflation process is monitored at one sample per second, for a maximum of 60 seconds. When the deflation process has been terminated, the computer then calculates the volume using the inflation flow rate data and the trapezoidal rule. The operator is then notified that that cycle has been completed. If additional runs have been entered by the operator, the computer prompts the operator to deflate the anti-G suit and proceed when the anti-G suit is ready for another inflation. This process continues until the last cycle has been completed.

SYSTEM VALIDATION To verify the volume calculations processed by the computer, a validation procedure was developed using an established method of volume determination. A wet spirometer was connected directly to the inflation apparatus in order to minimize the possibility of air leaks during the interconnections of the anti-G suit between the inflation apparatus and wet spirometer. This also allows for two separate volume calculations for one inflation cycle. The established method (spirometer) was used to gauge the accuracy of the proposed method (trapezoidal integration process). The operation of the computer monitoring system was the same as for the pressure garment, except the spirometer was substituted for the pressure garment. Also, an adjustable ball valve was substituted for the anti-G valve in order to allow for greater control of the inflation process. A total of nineteen inflation runs ranging from 24 to 37 liters were conducted. A Student's paired t-test was used to demonstrate that the difference between the two methods of volume calculations was not significant and that the proposed computer trapezoidal integration method closely imitated the spirometer volume determination method. These results are shown in Table 1.

Table 1. Statistical Difference Between Spirometer and Computer Calculated Volumes

	MEAN	Std Dev		
SPIROMETER	26.56	3.09		
COMPUTER	26.52	2.92		
DIFFERENCE	0.04	0.33	t=0.55	p=0.59
PERCENT DIFFERENCE	0.11	1.21		

The trapezoidal integration method had a difference no greater than 2.25% from the spirometer volume measurement for the nineteen trials, with most instances less than 1.5% difference. A graphical comparison between the two sets of data, shown in Figure 3, plots the volume results, with the ideal case being the equation of the line Y=X. Coordinates of plotted points

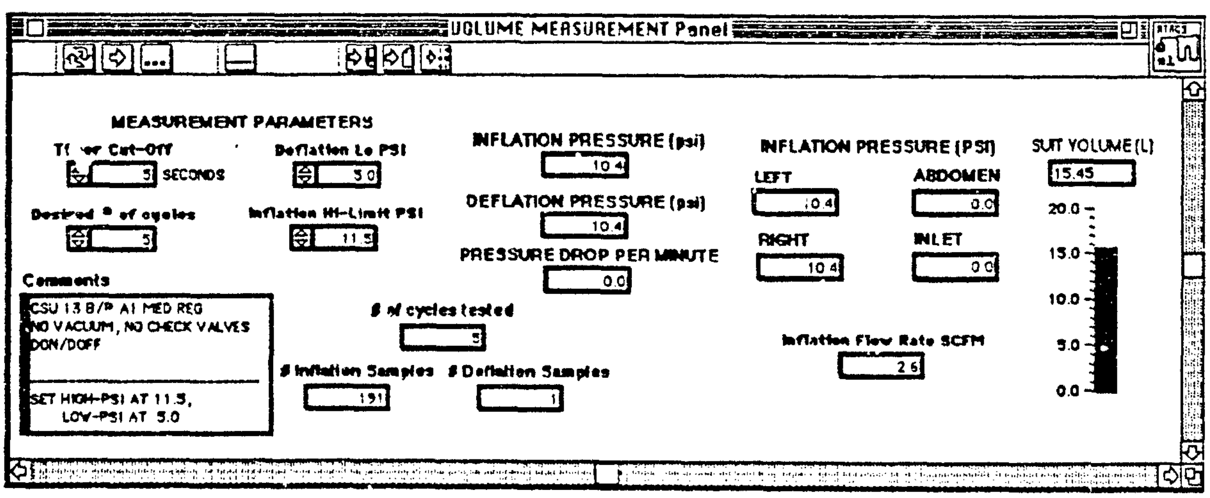

Figure 2. Panel 1

represent the two volume calculations for one inflation. As can be seen, the data points fall along the ideal line equation, further validating the proposed volume determination system.

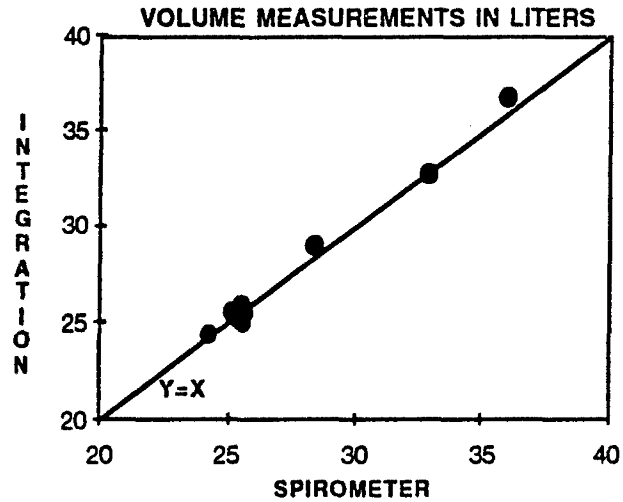

Figure 3. Comparative Results

CONCLUSION The proposed computer integration method has proven to be a reliable means of determining the volume required for inflation, as well as monitoring the inflation and deflation characteristics of a pressure garment. Additional advantages for using this system include overall efficiency; ranging from data management to time required for volume determination. Since the process is computer controlled, the program can be modified to meet the specific needs of the operator.

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BIOGRAPHIES

Ricardo Perez III is a research engineer for KRUG Life Sciences, San Antonio Division. He received his bachelors degree in Electrical Engineering from the University of Texas at San Antonio. Current responsibilities include providing engineering support for the testing of acceleration equipment and prototype acceleration garments in the Armstrong Laboratory Acceleration Research Branch.

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Philip J. Preen, 1Lt, USAF, BSC is a biomedical research engineer assigned to the Aeromedical Research Function of the Armstrong Laboratory at Brooks AFB, Texas. He received his bachelor's degree in Electrical Engineering at the University of South Florida. His responsibilities include the designing of unique instrumentation systems and creating experimental protocols to evaluate the effectiveness of medical equipment for use in aeromedical evacuations.